ISLAND FOX MONITORING AND DEMOGRAPHY ON SAN NICOLAS ISLAND—2010

FINAL REPORT

Prepared For

NAVAIR Ranges Sustainability Office, Code 52F00ME, Point Mugu, California

Under Cooperative Agreement No. N62473-07-2-0018

And

Naval Facilities Engineering Command, Southwest
San Diego Naval Station, San Diego, California

May 2011

ISLAND FOX MONITORING AND DEMOGRAPHY ON
SAN NICOLAS ISLAND–2010

FINAL REPORT

Prepared By

David K. Garcelon
Brian R. Hudgens

Institute for Wildlife Studies
P.O. Box 1104
Arcata, California 95518

Prepared For

NAVAIR Ranges Sustainability Office, Code 52F00ME, Point Mugu, California

AND

Naval Facilities Engineering Command, Southwest
San Diego, California
Agreement No. N62473-07-2-0018

May 2011

Recommended citation:

Garcelon, D. K. and B. R. Hudgens. 2011. Island Fox Monitoring and Demography on San Nicolas Island–2010. Unpublished report *prepared by* the Institute for Wildlife Studies, Arcata, California. 28 pp.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

This report summarizes annual monitoring of island fox (*Urocyon littoralis*) on Naval Base Ventura County, Outlying Landing Field San Nicolas Island, California (hereafter, San Nicolas Island). The island fox is listed as threatened by the state of California (California Department of Fish and Game 1987), and the subspecies occurring on San Miguel, Santa Rosa, Santa Cruz, and Santa Catalina islands are federally listed as endangered. The San Nicolas Island fox is believed to be particularly susceptible to disease due to its high densities and low genetic diversity.

Since 2000 the U.S. Navy has supported annual monitoring of fox population size and demographic rates. From 2000 through 2010 that monitoring has been conducted by the Institute for Wildlife Studies (IWS). IWS has trapped and marked foxes on three long-term study grids situated in the major habitats comprising 18% of the island (inland dunes, desert scrub and grassland). As in previous years, there was substantial variation in fox numbers among the grids, with the highest capture success (83.1%), numbers of adult foxes captured (76), and estimated population size (80) occurring on the westernmost grid (Redeye) and lowest (25.6% capture success, 21 adults captured, estimated population size of 23) on the westernmost grid (Skyline). Fox numbers decreased substantially on Redeye and Tuft's grids while increasing slightly on Skyline grid in 2010. The overall number of adults captured on the three grids dropped by 26% from the 2009 totals. We again used two methods to estimate grid-specific fox densities, one using population estimates from mark-recapture analysis and mean-maximum distance moved of recaptured animals, and another using spatially explicit mark-recapture methods. The latter method yielded lower density estimates which were consistent with what would be expected from previous home-range studies.

Adult apparent survivorship dropped significantly from 2009-2010 on the two western grids, with Tuft's dropping from 0.695 to 0.428 and Redeye dropping from 0.876 to 0.553. Juvenile survival dropped from all three grids combined dropped from 0.852 to 0.359. Initial analyses found no relationship in the survival of foxes related to their capture in leg-hold traps during the extensive trapping effort that occurred in 2009 to remove feral cats. When looking at the entire 11 year data set there is support for a negative density dependence effect on adult survival, where adult survival decreases as density increases.

Productivity was moderate in 2010 but there was a high pup to adult female ratio. The greatest number of pups were produced on the Skyline grid, which supports the lowest density of adult foxes. There is support of a density dependent effect of adults on pup production/survival.

We again tested foxes for recent exposure to three canine pathogens and documented the presence of canine distemper (43.8% prevalence), canine adenovirus (75% prevalence) and canine parvovirus (10.4% prevalence).

We advocate continued monitoring of island fox population dynamics and survivorship to provide for the early detection of novel threats, such as an epidemic. To this end, we recommend that annual monitoring efforts be supplemented with frequent (e.g., daily) survival monitoring of a subset of foxes, and continued vaccination against canine distemper and rabies. We also recommend studies on San Nicolas Island foxes directed at understanding environmental drivers of fox productivity and spatial variation in fox densities.

INTRODUCTION

The island fox (*Urocyon littoralis*) is California's only endemic carnivore, with a range limited to six of the eight California Channel Islands (Moore and Collins 1995). Despite its small size—it is the smallest fox species in the United States—it is the largest native terrestrial mammal found on the California Channel Islands. Morphological and molecular studies (Collins 1982, 1993; Gilbert *et al.* 1990, Wayne *et al.* 1991, Goldstein *et al.* 1999) justify the current classification of the island fox as a separate species from the mainland gray fox (*U. cinereoargenteus*; Wilson and Reeder 1993) and support the classification of a separate subspecies for each island (Hall 1981, Moore and Collins 1995). The island fox is listed as threatened by the state of California (California Department of Fish and Game 1987), and the subspecies occurring on San Miguel, Santa Rosa, Santa Cruz, and Santa Catalina islands are federally listed as endangered (Federal Register: Volume 69, Number 44, Pages 10335–10353).

In early 2000, foxes on San Nicolas Island (*U. l. dickeyi*) and those on San Clemente Island, California (*U. l. clemente*) were considered to be the only subspecies maintaining viable populations (Suckling and Garcelon 2000). The four remaining subspecies suffered marked declines in the mid to late 1990s. The subspecies on all three northern California Channel Islands (Santa Cruz, San Miguel, and Santa Rosa) were in imminent danger of extinction owing to predation by golden eagles (*Aquila chrysaetos*; Roemer *et al*. 2001) and the Santa Catalina Island subspecies, declined from an estimated 1300 in 1989–90 (Roemer *et al.* 1994) to about 100 as a result of an outbreak of canine distemper virus that swept through the population in 1999 (Timm *et al*. 2009). Fortunately, captive breeding programs on all four islands have been successful, and releases of captive-born foxes to the wild began in 2004. Island-wide trapping results in 2004 indicated that both subpopulations on Santa Catalina Island had reached the recovery goal set by Kohlmann *et al.* (2003, 2005) of at least 150 individuals in each subpopulation. Based on the trapping results, the subpopulations were considered recovered and a decision was made to close the captive breeding facility and release all captives to the wild.

The aforementioned declines of island fox subspecies emphasize the importance of monitoring population parameters of the San Nicolas Island subspecies. In the summer of 2000, the Institute for Wildlife Studies (IWS) began a fox-monitoring program on San Nicolas Island by establishing three capture-recapture trapping grids to evaluate the current status and demography of the subspecies and to monitor changes in population parameters. Trapping on the grids has been repeated each year since 2000 (Juola *et al.* 2002, Schmidt and Garcelon 2003, 2004, Garcelon and Schmidt 2005, Schmidt *et al.* 2006, 2007, Garcelon and Hudgens 2009, Hudgens and Garcelon 2010).

The monitoring program took on added importance in 2010 as part of a larger monitoring program to assess potential impacts of island-wide feral cat (*Felis catus*) removal on the fox population. From June 2009 through February 2010 leg-hold traps were used to remove feral cats from the island. During this time, 452 foxes were captured 994 times in leg-hold traps (Garcelon 2010, Hanson et al. 2010; IWS unpublished data). While any foxes requiring medical attention related to their capture were attended to (Garcelon 2010), the potential short-term and long-term impacts (both positive and negative) are being investigated through continued monitoring.

This report describes results for the 2010 trapping session. Where appropriate, comparisons are made with the results from the ten previous years of monitoring.

STUDY AREA

San Nicolas Island is the westernmost of the four southern California Channel Islands (Fig. 1). San Nicolas Island has been owned and operated by the United States Navy since 1933 and is closed to the public. At approximately 98 km from coastal Ventura County, California, it is the farthest of the eight California Channel Islands from the mainland. The 58-km^2 island is approximately 13 km long and 5.5 km wide with elevation ranging from sea level to 278 m. It is the fourth smallest Channel Island, larger only than San Miguel, Santa Barbara, and Anacapa islands. The island is roughly a plateau, with arroyos cutting down to the shoreline. The island is composed primarily of coastal scrub habitat (42% of island area), barren areas (24%), and grassland habitat (12%) (Halverson *et al.* 1996). From west to east, the sampling grids (Fig. 2 & 3) are dominated by coastal scrub and inland dune habitats (Redeye grid), coastal scrub (Tuft's grid), and grassland and coastal scrub (Skyline grid). The combined area (*i.e.*, the area created by connecting the outer trap locations of each grid) of the three grids was 6.7 km^2 or 11.6% of the total island area. The combined effective trap area (see Methods section for definition) for the grids in 2006 was 10.6 km^2 or approximately 18% of the total island area (Fig. 3). The Tuft's grid contains the greatest density of coyote brush (*Baccharis pilularis*) and coast goldenbush (*Isocoma menziesii*) and both the Tuft's and Redeye grids contained high densities of *Lupinus* and *Astragalus* species and the exotic sea fig or ice plant (*Carpobrotus chilensis*), which foxes are known to consume.

METHODS

Trapping and Handling

Foxes were trapped on the same three rectangular demography grids (Tuft's, Skyline and Redeye grids; Fig. 2 & 3; Table 1; Appendix A) used since the start of the fox monitoring program in 2000. Traps (23 x 23 x 66 cm box traps, Tomahawk Live Trap Co., Tomahawk, WI) on all three grids were placed at 250-m intervals and opened for six consecutive nights. Traps were baited with dry cat food, and a loganberry paste attractant (On Target A.D.C., Cortland, IL). Traps were covered with burlap and vegetation to provide protection from the sun and wind, and the bottoms were lined with grass to cover the metal of the trap and as bedding material for captured foxes (Figure 1).

Figure 1. Box trap set on grid for capturing foxes. Photo by D. Garcelon.

Traps contained "bite bars" (20-cm section of 1.3-cm-diameter polypropylene tubing attached to the inside of the trap with flexible wire) that captured animals could bite without damaging their teeth. As foxes routinely dig under traps to retrieve the bait when it falls through the mesh floor, a piece of plastic was placed behind the treadle to prevent it from falling out of the trap.

Data recorded on the first capture of each fox included date, grid name, trap number, passive integrated transponder (PIT) tag number (used as a unique identifier), sex, weight (to nearest 0.025 kg), ectoparasites (fleas, ticks, lice, ear mites) present, eye condition, reproductive condition and tooth condition (Figure 2). If an animal was not previously tagged, a subcutaneous PIT tag was inserted between and just anterior to the scapulae using a single-use sterile needle and syringe.

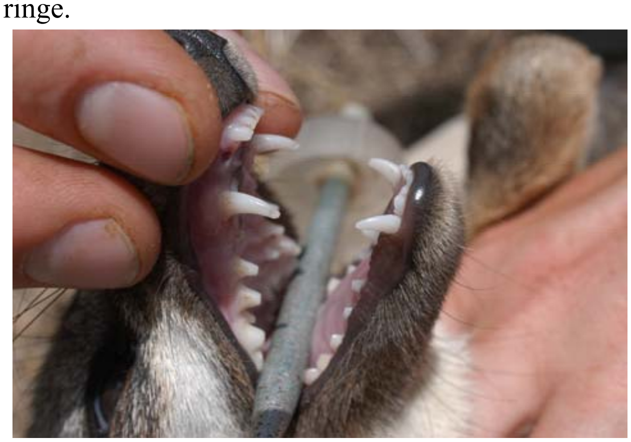

Figure 2. Inspecting the dentition of an island fox. Photo by D. Garcelon

Foxes were aged according to tooth eruption and dentin exposure patterns relating to wear on the first upper molar (Wood 1958, Collins 1993) and assigned to one of five age classes. Foxes were classified as pups (age class 0), or to one of 4 adult age classes: yearlings (1-4 years; age class 1), young adults (1-6 years; age class 2), mature adults (1-6; years; age class 3) and old adults (2-9; age class 4). Foxes were also assigned a relative body condition (1-5), with a 1 being a skinny animal with little or no body fat and a 5 being obese. We also noted any injuries or physical abnormalities, including those that appeared to have been related to the animal's capture.

A subset of foxes captured on all grids were vaccinated against canine distemper virus and rabies virus. Ear mites were collected from a sample of the foxes captured to aid in an inter-island study on the effect of these ectoparasites on fox health.

Up to 10 ml of blood was collected from the femoral vein or artery or jugular vein of select foxes for genetic and serologic analysis, and feces were collected when available. Serum was extracted from whole blood after centrifugation using a sterile pipette. Serum samples were split into 1 ml aliquots, each of which were placed in a 1.8-ml cryovial prior to freezing.

Analyses

<u>Population Size, Density, Growth Rate, on Demography Grids</u>

We used Pollock's robust design (Pollock 1982, Pollock *et al.* 1990, Kendall *et al.* 1995, Kendall 2001) within program MARK (version 5.1, White and Burnham 1999) to estimate adult fox population size (> age class 0) on each demography grid from adult capture histories on that grid. Adult capture histories represent the trapping days on which an animal was captured during grid trapping. The analysis assumes that fox populations are demographically closed (*i.e.*, no significant natality, mortality, immigration, or emigration occurs during the trap period) within a trapping session but allows for open populations between years.

We estimated adult population size using the Huggins estimator. We ran several models which differed in their assumptions about how daily capture and recapture probabilities, annual temporary dispersal, and annual survival probabilities varied from year to year and among grids. Based on previous analyses, we assumed daily capture and recapture rates were constant within a trapping session, but tested models allowing these parameters to vary from year to year and by grid. Temporary dispersal parameters account for animals that occasionally inhabit a grid, but may not be present on the grid during a trapping session (e.g., an animal whose home range shifts from year to year near the edge of the grid). Because there were few occasions of an animal trapped one year, missed the subsequent year and later trapped on the same grid, we limited analyses to models which had constant emigration and return rates across grids and years, and models which allowed emigration rates to vary by grid. Finally, we tested models for which adult survival varied by grid, by year, or both.

We estimated population size (and confidence intervals) as the weighted average of the models receiving the most support from the data as determined using AICc (Akaike's Information Criteria corrected for small samples) weights reported by program MARK. AICc weights represent the probability that a given model is the best approximation of the true description of the data among those models tested. This method of model averaging accounts for both uncertainty in parameter estimates from a given model and uncertainty about which model best fits the data (*i.e.,* best describes the biological processes producing the data).

For each grid we used the density estimator, D=N/A, where N is the estimate of the grid population size (from program MARK) and A is the area influenced by the trap grid. This area was the sum of the grid perimeter area and an additional strip around the grid perimeter; the strip width was calculated from an estimate of the mean maximum distance foxes moved (MMDM; Wilson and Anderson 1985) between captures that was generated by program DENSITY. Pups (age class 0) were excluded from estimates of population size and density due to their close association with adults—the relatively short movements of the less mobile pups could decrease the MMDM, resulting in a smaller area of influence and inflated density estimates.

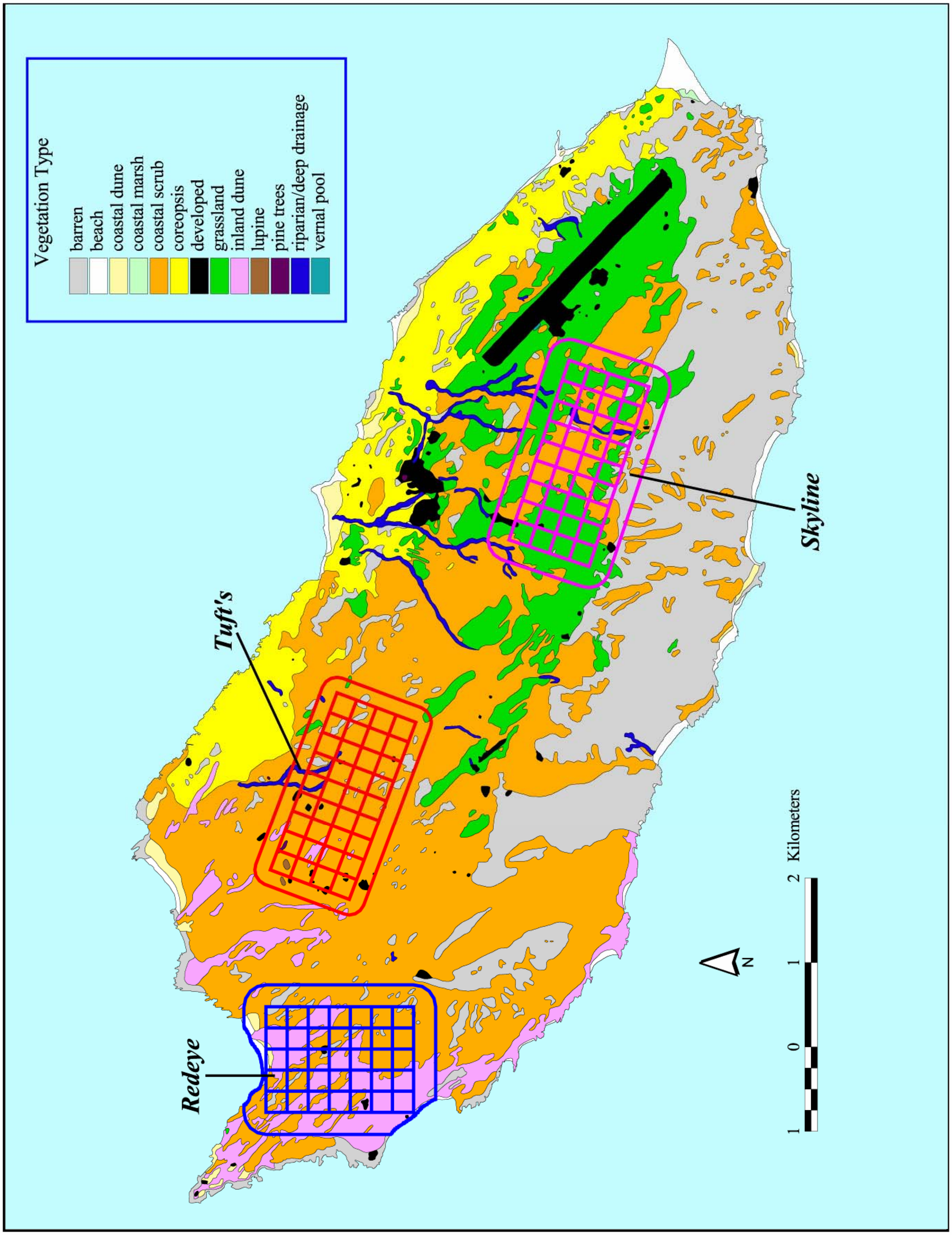

Figure 3. Island fox demography grid locations and effective trap areas (polygon surrounding each grid), at Naval Based Ventura County, San Nicolas Island, California. Vegetation map from Halverson et al. (1996).

Table 1. Island fox demography grid descriptions, Naval Base Ventura County, San Nicolas Island, California.

Grid	No. of traps	Grid configuration	Inter-trap distance (m)	No. of nights trapped	Perimeter area (km^2)[a]	% of total island area[b]	Primary vegetation types within grid perimeter (within effective trap area for 2006)[c]
Redeye	48	6 x 8	250	6	2.19	3.8	47% (42%) inland dune; 46% (49%) coastal scrub; 5% (5%) barren
Skyline	50	5 x 10	250	6	2.25	3.9	52% (52%) grassland; 43% (38%) coastal scrub; 3% (7%) barren
Tuft's	50	5 x 10	250	6	2.25	3.9	90% (89%) coastal scrub; 4% (4%) barren; 2% (2%) inland dune

This year we again used program DENSITY (Efford et al. 2004) as a second method of estimating island fox population density for each of the grids. Program DENSITY applies spatially explicit capture-recapture, using the locations where each animal is trapped to fit a spatial model of detection. The resulting estimate of population density are unbiased by edge effects and incomplete detection. We used the maximum likelihood option within program DENSITY to the spatial detection model.

Population growth rates (λ) for the demography grids were calculated as $\lambda = N_{t+1} / N_t$, where N_t is population size (or density in this case) at time t. Thus, $\lambda < 1$ indicates the population is declining, $\lambda > 1$ indicates the population is increasing and $\lambda = 1$ indicates a stable population. To provide the Navy with a long-term prospective to the status and trends of the fox population we have added data collected by IWS from 2000 through 2008.

Apparent Survivorship

We also used program MARK to estimate annual survivorship. Because mark-recapture data cannot distinguish between mortalities and permanent dispersal from trapped areas, estimated survival rates are really apparent survivorship, i.e., the probability that an animal captured on a grid neither dies nor permanently disperses to untrapped areas in the following year. Hereafter, we will refer to apparent survival simply as survival. Our analysis this year focused on assessing what biological factors (e.g., age, gender) are associated with variation in fox survivorship. Models were evaluated in program MARK using the Huggins estimator for data taken according to Pollock's robust design. To facilitate comparisons with previous years, we calculated survival estimates as an island-wide parameter. Since we were not interested in accommodating dispersal among grids in these analyses, we did not use the multi-strata analysis. Instead, we combined capture histories for all animals captured on any of the grids. This simplified the model structure, facilitating analyses by sex and age-class, while still accounting for temporary emigration from trapped areas.

Our first steps were to reduce the possible number of different models describing different assumptions about capture and recapture probabilities, and temporary emigration from and return to trapping grids. Each fox was categorized as either captured first as a pup (age class 0) or first as an adult (age class 1-4). We then estimated parameter values for several models of survivorship, temporary emigration from and return to sampled areas, and probability of capture or recapture. We then determined the most parsimonious model of capture/recapture probabilities, assuming survivorship varied by age class, gender, and year, and that dispersal varied by age. The most parsimonious model was judged as the model with the lowest corrected Akaike's Information Criterion (AICc) score that did not result in nonsensical parameter estimates (e.g., one with values <0 or >1 within the 95% confidence interval). The AICc score is calculated as the negative log-likelihood of a model given the data penalized by the number of parameters in the model

(Akaike1973; see White and Burham 1999 and Johnson and Omland 2004 for reviews).

We tested models allowing capture and recapture probabilities to vary by age at first capture, sex, and year, and all combinations of these three variables. After determining the most parsimonious model for capture/recapture probabilities, we determined the most parsimonious model structure for temporary dispersal on and off grids assuming survivorship varied by age class, gender and year, and capture and recapture probabilities varied by age at first capture and year (the best fit model from the analysis above). We began this process by varying assumptions about return probabilities to trapping grids, assuming temporary emigration varied by age and sex. We then varied assumptions about emigration rates assuming constant return rates based on the results from our examination of return probabilities.

Finally, we varied assumptions about whether survivorship varied by age class, gender, and year. Unlike capture-recapture and return probabilities, there was not a single model of emigration probabilities that was clearly superior to other models (see below). We therefore assessed models of survivorship assuming the most parsimonious model for capture-recapture probabilities and return probabilities, and the top two models of emigration probabilities to ensure conclusions about fox survivorship were robust to assumptions about temporary emigration.

In order to estimate survivorship for each year (2000–2009), we calculated a weighted average of the survivorship estimates from all models included in the top 95th percentile of AICc weights.

Testing for Exposure to Canine Diseases

We collected blood samples from 47 foxes to test for exposure to canine adenovirus (CAV), canine distemper (CDV) and canine parovirus (CPV). These viruses were selected due to their epidemic potential and possible fatal outcomes in susceptible individuals. These diseases were also selected because island foxes on San Clemente Island were monitored for exposure to these diseases in 2007 (Garcelon et al. 2008). Blood was collected in the field using veinapuncture and the sample was placed in a tube and allowed to clot. While in the field the blood was kept cool using ice packs. The sample was later separated by centrifugation and the serum pipetted off and frozen in cryotubes. The samples were sent for testing to the Animal Health Diagnostic Center at Cornell University in Ithaca, NY.

RESULTS

Capture Statistics

We captured 112 adult foxes (51 males, 61 females) and 31 pups (15 males, 16 females) a total of 368 times on three grids (Table 2). The number of adults captured was considerable lower than the 156 captured in 2009, although pup production was up. Only two adult foxes were captured on the grids had not been previously PIT tagged. We believe this was primarily associated with the large proportion of the population that was PIT tagged in 2009 in association with a feral cat trapping program.

Capture success for the three grids averaged 52.8% (Table 2). Foxes were captured an average of 2.6 times. Only two foxes were captured on more than one grid during the sampling period. Two males, age classes 2 and 4, were captured on both Tuft's and Redeye grids. No feral cats were captured in 888 trap-nights or observed during any of our field activities.

Age structure varied across the three grids, with age class 2 making up the largest proportion of adults for each grid (Fig 4). There were fewer age class 3 and 4 individuals on the Tuft's grid and fewer age class 3 foxes on the Redeye grid relative to 2009 (Fig. 4; see discussion).

We obtained blood samples from 89 foxes (40 from Redeye, 34 Tuft's, 15 Skyline). We inoculated or boostered 44 foxes against canine distemper and rabies viruses (Skyline 6, Tuft's 17, Redeye 21).

Physical Condition

In a general assessment of body condition (scale of 1-5, with 1 being thin and 5 being obese), 70% of the foxes examined were in average to good condition, and 17% were considered thin or in poor condition. The remaining 13% were considered in very good condition.

There was a significant difference in body weight of females among grids ($P = 0.032$; $F = 3.59$; $df = 2$), with the females on Tuft's having the lowest average body weights (Table 3). Weights of males also differed significantly among grids ($P = 0.022$; $F = 4.0$; $df = 2$), but there was no difference when just Tuft's and Redeye males were compared ($P = 0.108$; $F = 2.65$; $df = 1$). Adult males on the Skyline grid had the lowest average body weights (Table 3).

Fleas (*Pulex irritans*) were found on only 2 foxes (1.2%); no ticks or lice were found on any captured foxes.

Table 2. Island fox demography grid trapping results, 2010, on Naval Base Ventura County, San Nicolas Island, California (see Fig. 2 or 3 for grid locations).

Grid	Dates open	No. Trap-nights	No. Adult males	No. Adult females	Total No. adults	No. Male pups	No. Female pups	Total No. pups	Total No. captures[a]	Capture success (%)[b]
Redeye	8/27–9/01	288	24	28	52	3	3	6	150	52.1
Skyline	7/06–7/11	300	10	14	24	7	7	14	101	33.7
Tuft's	8/04–8/09	300	20	19	39	5	6	11	117	39.0
		Total	54[c]	61	115	15	16	31	368	41.4

[a]Includes recaptures.
[b]Calculated by dividing total number of captures by the number of trap-nights.
[c]Three male foxes were caught on two different grids, so total number of individual males in 51.

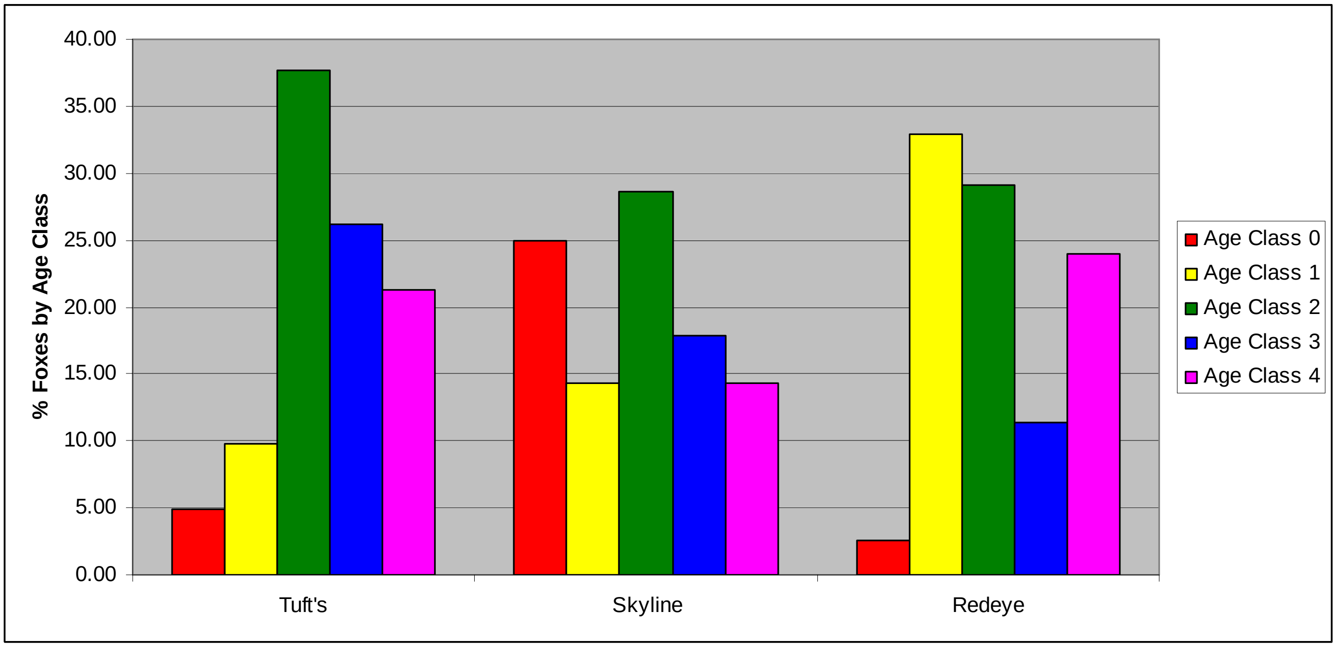

Fig. 4. Age class distribution by demography grid, 2010, on Naval Base Ventura County, San Nicolas Island, California. Age class is based on tooth wear patterns on of the first upper molar, with age class 0 being pups and increasing wear placing animals in age classes 1-4.

Table 3. Mean weight (kg) of adult island foxes captured on grids, 2010, on Naval Base Ventura County, San Nicolas Island, California.

Grid	Sex	*n*	Mean	SD
Redeye	M	20	1.84	0.165
	F	22	1.63	0.230
Skyline	M	9	1.75	0.223
	F	13	1.64	0.181
Tuft's	M	16	1.69	0.191
	F	17	1.51	0.110
All foxes combined	M	45	1.76	0.194
	F	52	1.60	0.191

The most common physical "abnormalities" noted for the 143 foxes captured on grids in 2010 were notched ears (6.3%), minor cuts or abrasions (3.5%), and injuries to their lips (generally torn away from the jaw; 3.5%) (Table 4). One fox was missing an eyeball, one was missing part of its tail, and five had corneal opacities. Three individuals (2%) broke one or more teeth while in a trap. However, we only inspected foxes thoroughly for trap-related injuries on their initial capture; therefore, it is possible that additional tooth breakage may have occurred upon subsequent recapture.

Table 4. Physical abnormalities of island foxes captured on grids, 2010, on Naval Base Ventura County, San Nicolas Island, California.

Physical "abnormality"	No. of foxes
Matted or missing fur	2
Minor cuts/abrasions	5
Notched or partial missing ear(s)	9
Broken tooth (trap damage)	3
Lip injuries	5

Productivity

Across all grids, 37 (60.6%; n = 61) of the females were either lactating or showed signs of having lactated this year. The pup to adult female ratio for all grids combined was quite high in 2010 0.51:1 (31 pups captured, 61 adult females captured) compared to 2009 (0.15:1). Reproduction was again concentrated on the Skyline grid, where an equal number of pups and adult females were captured, yielding a pup:adult female ratio of 1:1.

Serology

In 2010 we submitted 48 serum samples collected from island foxes to test for antibody titers to canine distemper virus, canine parvovirus and canine adenovirus. Eleven of the samples submitted for analysis were from individuals that had also be bled and tested in 2009, allowing for some comparisons across years. Positive antibody titers for canine distemper virus were found in 43.8% of the individuals tested, but two of those foxes had previously received canine distemper virus vaccine, and discounting those resulted in a 39.6% seroprevalence (Appendix B). For canine parvovirus we found a 10.4% seroprevlence and for canine adenovirus 75% of the samples tested positive. Of the 11 individuals that were sampled in both 2009 and 2010, canine adenovirus titers either remained unchanged (36%) or increased (64%) (Appendix B).

Movements

Between 2009 and 2010, two tagged foxes moved from Redeye to the Tuft's grid, and two moved from the Redeye to the Skyline grid. All of these individuals were males. As the Redeye and Tuft's grids are not a great distance apart, these may not have been permanent changes in home ranges. Three foxes, all males, were captured on two different grids in 2010. Two were captured on both Redeye and Tuft's grids, and one was captured on Skyline and Tuft's grids.

Population Size, Density, Growth Rate, and Apparent Survivorship on Demography Grids

Adult fox population size estimates ranged from 25 on the Skyline grid to 56 on the Redeye grid (Table 5). Population size estimates for 2010 indicate the number of adult foxes on the Tuft's and Redeye grids decreased substantially from 2009, while on Skyline grid estimate increased slightly (Fig. 6-8). The mean annual rate of adult population change (λ) for 2009–2010 was 0.71 for Redeye and 0.57 for Tuft's. On the Skyline grid the population growth was positive with a value of 1.07.

Density estimates using values from program MARK/MMDM ranged from 5.3 foxes/km^2 on the Skyline grid to 14.4 foxes/km^2 on the Redeye grid (Table 5). Continuing the trend shown in the past, density estimates using program DENSITY provided lower values for all three grids when compared to density calculated from program MARK, although there was overlap in the 95% confidence intervals of the estimates for all three grids for the two methods (Tables 5 & 6). The results for 2010 using program DENSITY were lower on all three grids compared to 2009, although Skyline was only slightly lower (Table 6). The lower density tracks the decrease in the number of adults captured and the decreased population estimates calculated for Tuft's and Redeye using program MARK.

Based on model selection using program MARK, the most parsimonious model for explaining apparent annual juvenile survival was combining all grids. Based on previous analyses (Hudgens and Garcelon 2010), we combined sexes to obtain the greatest power in the model. Juvenile survival dropped substantially in 2010 compared the previous four years of monitoring (Fig. 5). Adult annual survival also decreased on the Tuft's and Redeye grids, while increasing on the Skyline grid (Figs. 6-8).

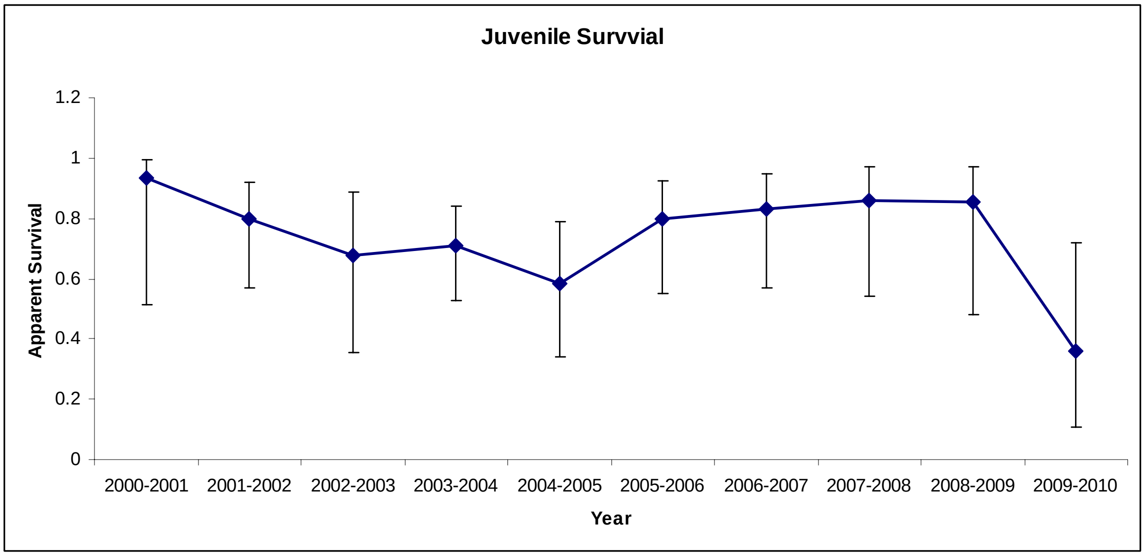

Figure. 5. Apparent survival of juvenile foxes for both sexes and all grids combined.

Table 5. Total number of adults captured, population estimates, effective trap area, and adult density estimates for the three demography grids, 2010, on Naval Base Ventura County, San Nicolas Island, California.

Grid[a]	No. Adults captured[b]	Population estimate	95% C. I.	Effective trap area (km^2)	Density estimate (foxes/km^2) based on population estimate[c]	Density estimate range based on 95% C.I. of population estimate (foxes/km^2)[d]
Redeye	52	56	53–69	3.89	14.4	13.6-17.7
Skyline	24	25	24–32	4.68	5.34	5.1-6.8
Tuft's	39	45	40–65	3.72	12.1	10.75-17.5

[a]See Fig. 2 or Fig. 3 for grid locations.
[b]One fox was captured on both Skyline and Redeye grids.
[c]Calculated as population estimate/effective trap area.
[d]Range calculated as population estimate/effective trap area, using the upper and lower bounds of the 95% C. I. of the population estimate.

Table 6. Island fox density calculated for 2008 – 2010 using program DENSITY with maximum likelihood function.

Grid[a]	No. adults captured	Maximum likelihood density (foxes/km^2)	SE	95% C.I. of density estimate	λ
Redeye 2008	65	15.9	2.27	12.2-21.2	
Redeye 2009	76	15.4	2.02	11.9-19.8	0.97
Redeye 2010	52	11.5	1.75	8.6-15.5	0.75
Skyline 2008	32	7.3	1.63	4.7-11.2	
Skyline 2009	21	3.53	1.13	1.9-6.5	0.48
Skyline 2010	24	3.3	0.93	1.9-5.7	0.93
Tuft's 2008	55	11.5	1.98	8.2-16.1	
Tuft's 2009	58	13.16	1.96	9.8-17.6	1.14
Tuft's 2010	36	8.54	1.50	6.1-12.0	0.65

[a]See Fig. 2 or Fig. 3 for grid locations.

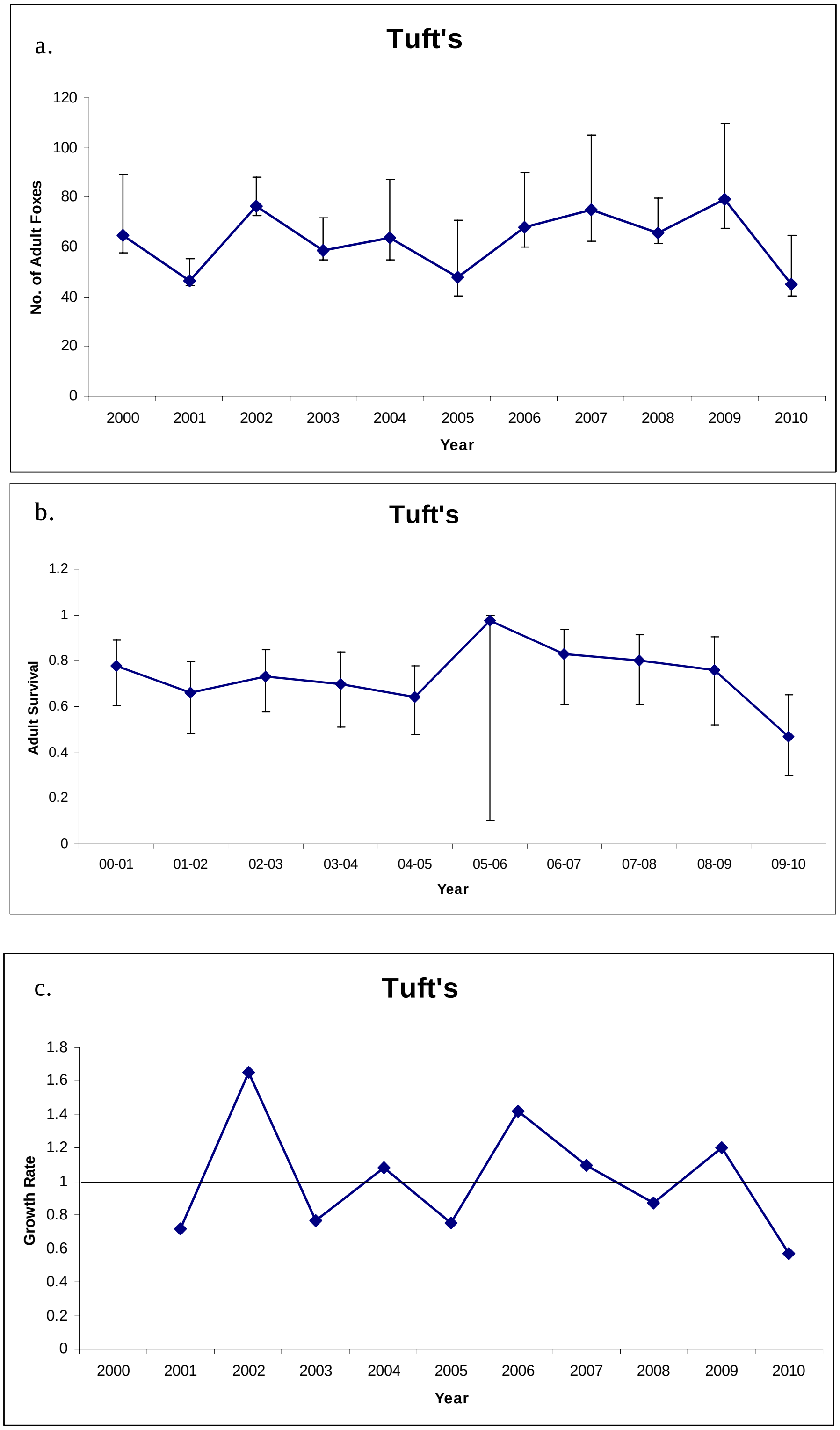

Fig. 6. Tuft's grid (a) adult population size and (b) apparent adult survival and (c) growth rate (λ) estimates 2000–2010, on Naval Base Ventura County, San Nicolas Island, California. Vertical lines represent 95% confidence intervals. A λ <1 indicates the population is declining and λ >1 indicates the population is increasing. A λ of 1 indicates a stable population (shown by horizontal line).

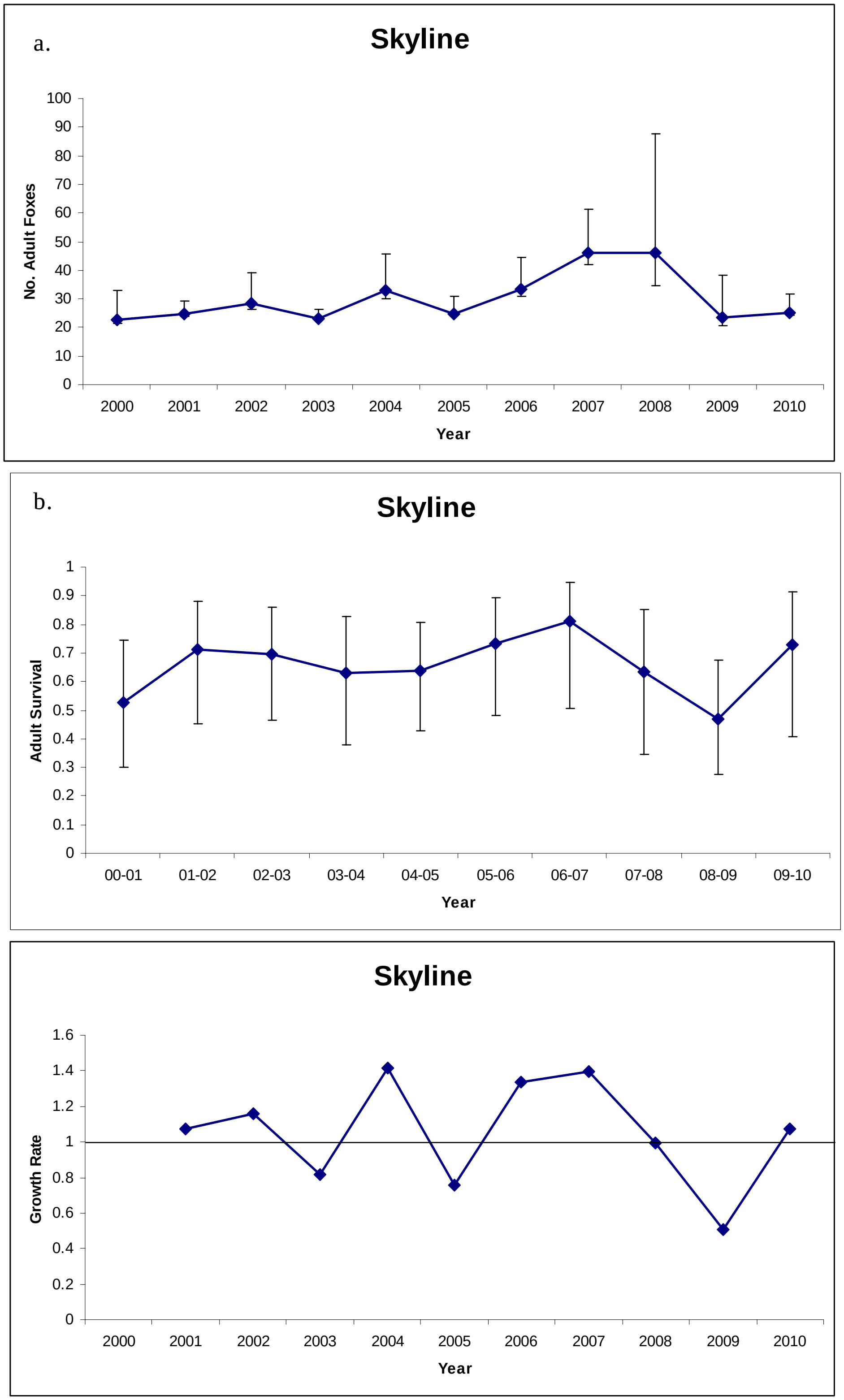

Fig. 7. Skyline grid (a) adult population size and (b) apparent adult survival and (c) growth rate (λ) estimates 2000–2010, on Naval Base Ventura County, San Nicolas Island, California. Vertical lines represent 95% confidence intervals. A λ <1 indicates the population is declining and λ >1 indicates the population is increasing. A λ of 1 indicates a stable population (shown by horizontal line).

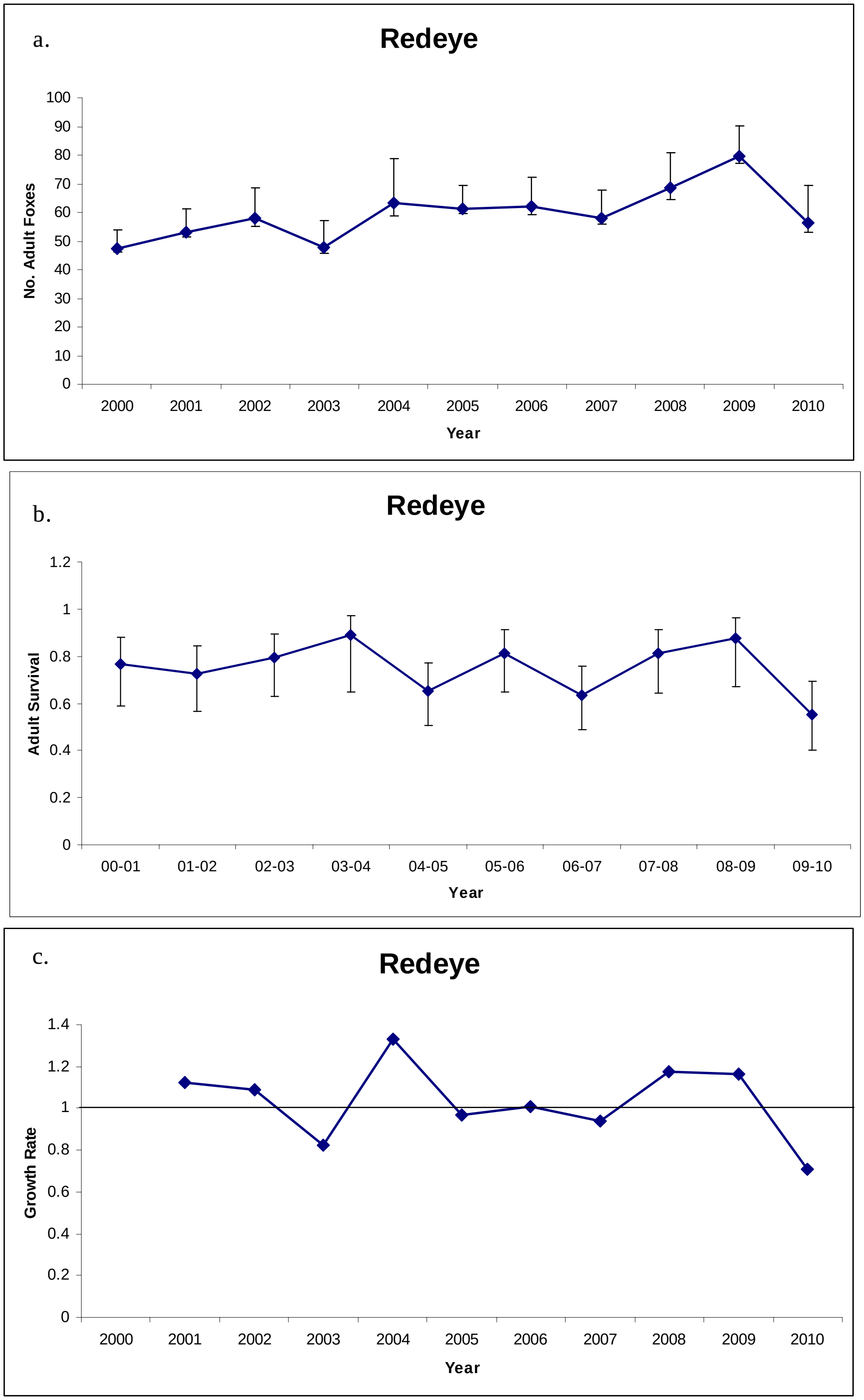

Fig. 8. Redeye grid (a) adult population size and (b) apparent adult survival and (c) growth rate (λ) estimates 2000–2010, on Naval Base Ventura County, San Nicolas Island, California. Vertical lines represent 95% confidence intervals. A λ <1 indicates the population is declining and λ >1 indicates the population is increasing. A λ of 1 indicates a stable population (shown by horizontal line).

DISCUSSION

Notable findings from trapping efforts in 2010 were: 1) the estimated population size of foxes on the Tuft's and Redeye grids had shown an approximate one-third decrease in size from 2009, 2) apparent adult survival on those grids had also decreased by approximately one-third, 3) different analyses of mark-recapture data yield different results for estimated population densities on the grids, 4) productivity was up on all grids compared to 2009, 5) there was a high ratio of adult females to captured pups, and 6) foxes were overall healthy, with low incidence of injury.

The number of foxes estimated from mark-recapture efforts on San Nicolas Island remained high in 2010, in spite of significant drops in the estimates for the Redeye and Tuft's grids. Capture success was lower on all three grids compared to previous years, but was greater than 33% for all grids and greater than the mean trap success for grids on San Clemente Island (Schmidt et al. 2004, Schmidt and Garcelon 2005).

Age structure of the fox population showed a shift toward slightly older individuals in 2010. This would be somewhat expected given the poor reproduction observed in 2009. There were fewer pups in 2009 that would have been likely classified as age class 1 in 2010. Similarly, at least a portion of those classified as age class 1 in 2009 would now be in the next age class. This was most apparent on the Redeye grid, where there were few age class 1 foxes but a high proportion of age class 2 foxes. While age class does not precisely track chronological age, if immigration of age class one animals does not occur then fewer pups produced on a grid may lead to changes in the age class structure. Redeye had 15 pups captured in 2008 and had the highest proportion of age class one individuals in 2009.

Estimates for population growth rates were similar for the two methods used for calculation (program MARK and program DENSITY). Both programs had two grids with negative growth. Redeye had values of λ=0.75 and λ=0.71 calculated from DENSITY and MARK, respectively (Table 6, Figs. 6 & 8). The Tuft's grid also showed negative growth (λ=0.65 and λ=0.57) (Table 6, Figs. 6 & 8). For the Skyline grid the values were still similar between the two methods of calculation, although program MARK showed positive growth (λ=1.07) and DENSITY indicated slightly negative growth (λ=0.93) (Table 6, Fig. 7).

Again this year we employed two different techniques to calculate fox density on the grids. The first is the method we have used for the previous ten years and is determined using two values; the population estimate derived from mark-recapture data using program MARK, and the effective trap area calculated using a formula which incorporates the movements of foxes during the trapping period (mean maximum distance moved - MMDM). Comparisons made on San Clemente Island between grid trapping-based density estimates (using MARK and MMDM buffers) and telemetry-based home range estimates found that the former resulted in a density that was biased high (Garcelon 1999, Schmidt *et al.* 2004). This appears to be associated with foxes moving shorter distances during the trapping period (likely due to the presence of food in the traps) and therefore the effective trap area is smaller than it should be to provide an accurate density estimate.

For the third year in a row, we used an additional method to estimate fox density on the grids. Rather than using the conventional buffer strip around a trapping grid that is determined by the target animal's movements or home range size, program DENSITY (Efford et al. 2004) uses the locations where each animal is detected to fit a spatial model of the detection process. As it is unbiased by "edge effects" or incomplete detection, it should provide a more accurate estimate of population density.

All of the density estimates derived from program DENSITY were lower than those calculated from the MARK/MMDM method. Estimates from program DENSITY were 20%, 38% and 29% lower than MARK/MMDM estimates for Redeye, Skyline and Tuft's, respectively. Using home ranges sizes determined by radio-telemetry for foxes on San Clemente Island, Schmidt et al. (2004) found that the MARK/MMDM method provided density estimates that were 19 – 55% higher than home range-based estimates. While similar telemetry data are not available for San Nicolas Island, if we assume similar behavioral response to trapping and comparable home range sizes, then the results from program DENSITY may be providing a more accurate estimate of fox density. However, extremely high capture success at high densities could lead to higher probabilities that the trap which first captured a fox, and adjacent traps, were occupied by another animal on subsequent days. A fox would then have to travel further to encounter an unoccupied trap than it would if densities (and consequently capture success) were lower. This could potentially result in an apparent increase in its home-range size estimated from the spatially explicit mark-

recapture analysis employed by program DENSITY. While program DENSITY has a great deal of promise as an unbiased estimator of fox densities on the grids, the influence of high fox densities on fox movement with respect to traps needs to be further examined before it is relied upon as the sole tool for estimating year-to-year changes in population size in high-density regions of the island.

If we chose to add one rather than ½ MMDM as the buffer for the grid to calculate effective trap area, the differences between the two estimation methods go to 20%, 4.2% and 4.5%, for the Redeye, Skyline and Tuft's grids, respectively. If the estimate from program DENSITY is providing a more accurate estimate of the actual fox density, then that would suggest that we have been applying too small of an effective trap areas when using the MARK/MMDM method. A telemetry study examining actual home range and overlap of foxes in specific areas would be required to help elucidate how well these programs are calculating fox density.

Most of the foxes we examined appeared healthy. We found no indications infectious disease in the fox population. Many of the physical anomalies that were observed in captured foxes were consistent with intra-specific aggression, such as minor cuts and abrasions, torn lips and ear tissue injuries. Injuries associated with intra-specific aggression are not uncommon in island fox populations and would be expected, especially in areas of such high fox density. The majority of the foxes (~83%) examined were in average to very good physical condition. During the summer months foxes will generally be lean, as was the case for most examined, but for the San Nicolas Island population it still equated to "good" condition for most animals. The occurrence of ~17% of the animals considered to be in poor body condition is not uncommon, as both older individual and females which had recently completed lactation can tend to be in poor body condition.

Annual apparent survival was the lowest we have observed on the Redeye and Tuft's grids since the start of the monitoring program, and this was consistent with the reduced number of adults captured on these grids (Figures 6 & 8).

There were relatively good pup production on the grids, and coupled with the lower number of adults on two of the grids resulted in a high adult female:pup ratio for 2010. A large number of female foxes were observed either lactating (8) or showing signs of having lactated this year (45), further supporting that a large percentage of the females at least attempted to rear litters. There appears to be a relationship between the number of adults present on the grid and number of pups captured, suggesting density dependence in pup production or survival into the summer trapping period (Fig. 9). Other factors, such as prey resource availability, likely influence pup production and survival as well, but density dependence may be playing an important role in population regulation.

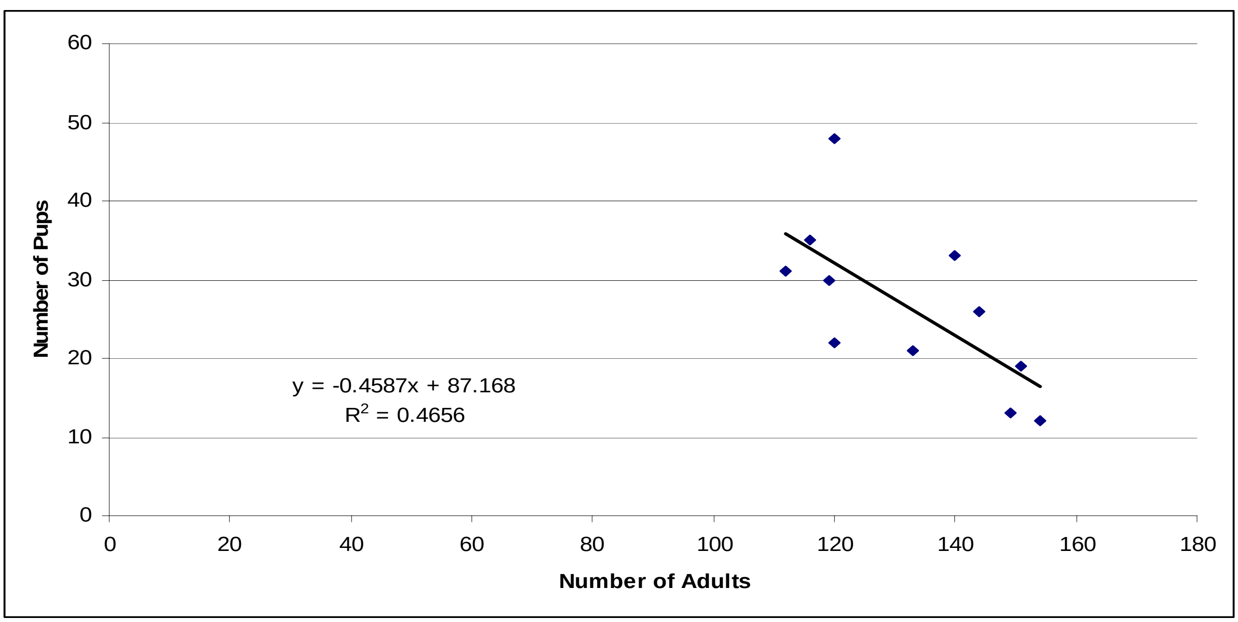

Figure 9. Relationship of adult foxes and pups captured per year on all three trapping grids combined.

Potential Explanations for Population Reduction on Western Grids

We examined the capture history of foxes that were trapped on the grids in 2008, and then went missing is 2009, to determine a baseline for the number of foxes expected to be lost from the population in each age class. We then examined the number of foxes captured in leg-hold traps by Island Conservation during their efforts to eradicate feral cats from the island (Hanson et al 2010). Finally, we looked at the proportion of foxes from each age class captured in 2009 on the fox grids that were trapped anywhere in the island, and whether or not they had been previously captured in a leg-hold trap. The results suggest that, in general, being captured in a leg-hold trap did not decrease survival of the foxes and an equal or greater number of foxes ended up missing from the population that were not trapped in leg-holds as those which were. The non-leg-hold captured fox sample size is fairly small for some age classes because a high proportion of the fox population was captured in leg-hold traps at least once. We will be looking specifically at the number of times foxes were captured in leg-hold traps, whether or not they were treated for injuries, and how those factors might have influenced survival, and reported those findings in another report.

One hypothesis for the decline on the two grids is the outbreak of a canine disease. The impact of an epidemic might be observed only in the western grids if that is the point of origin, or if the spread of the disease was hindered in Skyline (or by reaching Skyline) by relatively low fox densities. Similar patterns in the change in age-class specific recapture rates between 2009 and 2010 in Redeye and Tuft's coupled with a generally more positive change in Skyline are consistent with disease. While results from the serological survey could be telling, we survey for exposure to only a small number of potential diseases, therefore negative results do not preclude disease from being a factor. However, lack of visibly sick animals among those captured during the extensive trapping throughout 2009 and 2010 argues against disease as a cause.

Negative density dependence on adult survival may also have come into play. If negative density dependence is in effect we would expect the greatest impacts on the Tuft's and Redeye grids where fox densities have been historically high. We would also expect there to have been a similar response (reduced adult survival) in the past when densities were high. We conducted an analysis of co-variance (ANCOVA) with grid and density which yielded significant effects of both these factors on adult survival. It appears the slope of the regression between adult density and adult survival is the same across the island, but the intercept is depressed for Skyline. This suggests negative density dependence in adult survival is being expressed in the population, and is contributing to the observed population decline. As shown in Fig. 9, density dependence may also be playing a role in reproductive success.

Serology Testing

Seroprevalence for canine parvovirus was zero in 2008, increased to 16% in 2009 and was 10% in 2010. This suggests there is an endemic strain of the virus on San Nicolas Island circulating at low levels in the population. Canine parvovirus can severely impact pups and therefore could have an impact on the population without affecting the adults. However, we would expect to see a rise in the seroprevalence as well as the antibody titers levels in the resident adults if a major outbreak of the disease occurred.

There were a greater percentage of foxes that tested seropositive for canine distemper virus in 2010 (39%) compared to 2009 (7%), but both were substantially lower than the 70% positive samples noted in 2008. While there was an increase in the seroprevalence from 2009, most positive titers were relatively low (1:4 or 1:6), which does not suggest that there had been out significant outbreak of disease. Two individuals had higher titers, but they were individuals that had been previously vaccinated for canine distemper virus (4777B in both 2008 and 2009; F5124 in 2008). It was encouraging to see that even for the individual that had not been vaccinated for two years, it had maintained a titer of 1:24.

Results for canine adenovirus titers in 2010 showed a large increase in seropositive individuals over 2009 (75% vs 44%). In 2008 the seroprevalence was 58%, so the percentage of seropositive foxes has remained high over the last three years suggesting the virus regularly circulates through the population. However, high seroprevalence of canine adenovirus is not uncommon is wildlife populations. In Texas, greater than 50% of the coyotes (*Canis latrans*) were found positive for canine adenovirus (Trainer and Knowlton

1968), 81% of wolves (*Canis lupus*) were found positive in Alaska (Zarnke and Ballard 1987), and in Scandinavia 59.6% of red foxes (*Vulpes vulpes*) and 37.8% of arctic foxes (*Vulpes lagopus*) tested positive for canine adenovirus (Akerstedt et al. 2010). In addition to the high seroprevalence there were more high titers (>1:1000) in 2010 than in 2009 (70% vs 32%), including 14% of the positive individuals having titers ≥1:12288. This may suggest that some animals became infected or had clinical disease associated with canine adenovirus and mounted a successful response to the virus. To further our understanding of whether island foxes are actively shedding virus, it would prudent to begin collecting nasal and ocular swabs from select individuals (especially those who are bled for serological testing) to look for canine adenovirus virus (D. Clifford, pers. comm.). These samples can be stored and do not require immediate analysis.

MANAGEMENT RECOMMENDATIONS

The largest risk currently facing San Nicolas Island foxes is the potential for an introduced disease to quickly decimate the population. San Nicolas Island foxes currently have two risk factors promoting susceptibility to an introduced disease. First, the sustained high density of foxes on the island represents a risk factor, as the persistence and spread of disease throughout a population is closely tied to population density (Anderson and May 1981, Finkenstadt and Grenfell 1998). San Nicolas Island foxes face a further risk since the population has extremely low genetic diversity (Aguilar *et al.* 2004); although they do report relatively high diversity in MHC genes which are closely associated with immune responses. Low genetic diversity can be associated with reduced disease resistance, increased risk severity, and length of disease epidemics in populations (Sprinbett *et al.* 2003). Levels of genetic diversity observed in San Nicolas Island foxes are caused by severe population bottlenecks leading to high levels of inbreeding. Such inbreeding is also associated with increased susceptibility to disease and environmental extremes (Keller and Waller 2002).

In order to reduce the risk of catastrophic disease, we incorporated a vaccination program associated with our trapping efforts. A percentage of the animals caught were given canine distemper and rabies vaccinations. Modeling work by V. Baker and D. Doak (personal communication) has shown that, if the vaccinations are highly effective, this type of vaccination program is the most effective way of preventing an epidemic of those diseases. This vaccination program does not, however, provide any protection from potential disease threats other than canine distemper and rabies, and may not protect against all strains. Future monitoring of disease prevalence should prioritize unvaccinated animals on grids, but should include grid animals vaccinated against canine distemper virus so that spatial differences of canine adenovirus and canine parvovirus prevalence can be evaluated in the context of changes in demographic rates and population size on the grids.

We also advocate within-year monitoring of fox survival, as demonstrated from 2006-2008 using an automated survival monitoring system (Hudgens et al. 2007, 2008), to provide for early detection of lethal disease outbreaks. Part of this monitoring program should include developing specific triggers, based on types and frequency of mortalities, to further management actions (Hudgens et al. 2007, 2008). An epidemic response plan developed for the San Clemente Island fox population (Hudgens et al. 2010) also advocates this type of combined vaccination and continuous monitoring program to help prevent a catastrophic decline such as that observed on Santa Catalina Island (Timm et al. 2009).

Continuing the fox monitoring program, in conjunction with additional monitoring associated with the post-removal of feral cats, will help us better understand the potential effects of cat removal on the island fox population. This long term monitoring program also help us examine the effects of rainfall patterns We also advocate building a better understanding of San Nicolas Island fox feeding and breeding ecology to address two questions. First, what is the role of introduced species in maintaining high fox densities on San Nicolas Island? Work conducted on the food habitat of San Nicolas Island foxes suggest that introduced food sources are some of the most important in diet of the foxes (B. Cypher, personal communication). Understanding whether these resources act to promote longevity, reproduction, or buffer populations from environmental variation will allow predictions of the continued spread or control of these species on San Nicolas Island will impact foxes. Secondly, how does breeding potential change with fox age? Understanding which foxes contribute the most to pup pro-

duction will help to elucidate whether some areas of the island act as population sinks (or sources). More importantly, such an understanding will provide information about mechanisms that maintain high fox densities but do not contribute to future fox generations. The answer to both questions will be necessary to make good predictions about how management of introduced food resources will impact foxes. Being able to separate and understand the roles of introduced species, and other island resources, in maintaining high population densities and contributing to future fox generations will allow the Navy to effectively manage these species without risking endangering San Nicolas Island foxes.

REFERENCES

Aguilar, A., G. Roemer, S. Debenham, M. Binns, D. Garcelon, and R. K. Wayne. 2004. High MHC diversity maintained by balancing selection in an otherwise genetically monomorphic mammal. Proceedings of the National Academy of Sciences 101: 3490–3494.

Akaike, H. (1973) Information theory as an extension of the maximum likelihood principle. In Second International Symposiumon Information Theory (Petrov, B.N. and Csaki, F., eds), pp. 267–281, Akademiai Kiado.

Almberg, E.S., L.D. Mech, D.W. Smith, J.W. Sheldon, R.L. Crabtree. 2009. A serological survey of infectious disease in Yellowstone National Park's canid community. PLoS ONE 4(9):e7042.doi:10.1371/journal.pone.0007042.

Åkerstedt, J., A. Lillehaug, I. Larsen, N.E. Eide, J.M. Arnemoand, and K. Handeland. 2010. Serosurvey for canine distemper virus, canine adenovirus, *Leptospira interrogans*, and *Toxoplama gondii* in free-ranging canids in Scandinavia and Svalbard. Journal of Wildlife Diseases 46: 474-480.

Anderson, R. M., and R. M. May. 1981. The population dynamics of microparasites and their invertebrate hosts. Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences. 291:451–524.

California Department of Fish and Game. 1987. Five-year status report on the island fox (*Urocyon littoralis*). Unpublished report, California Department of Fish and Game, Sacramento, California. 7pp.

Clifford, D.L., J.A.K. Mazet, E.J. Dubovi, D.K. Garcelon, T.J. Coonan, P.A. Conrad and L. Munson. 2006. Pathogen exposure in endangered island fox (*Urocyon littoralis*) populations: implications for conservation management. Biological Conservation 131: 230-243.

Collins, P. W. 1982. Origin and differentiation of the island fox: a study of evolution in insular populations. M. A. thesis, University of California, Santa Barbara. 303pp.

Collins, P. W. 1993. Taxonomic and biogeographic relationships of the island fox (*Urocyon littoralis*) and gray fox (*U. cinereoargenteus*) from Western North America. Pages 351–390 *in* F. G. Hochberg, editor. Third California Islands Symposium: Recent advances in research on the California Islands, Santa Barbara Museum of Natural History, Santa Barbara, California.

Efford, M.G., D.K. Dawson and C.S. Robbins. 2004. DENSITY: software for analyzing capture-recapture data from passive detector arrays. Animal Biodiversity and Conservation 27.1: 217-228.

Finkenstadt, B., and B. Grenfell. 1998. Empirical determinants of measles metapopulation dynamics in England and Wales. 265:211–220.

Garcelon, D. K. 1999. Island fox population analysis and management recommendations. Unpublished Report submitted to: Southwest Div., Naval Fac. Eng. Command, San Diego, California. 57pp.

Garcelon, D. K. 2010. Annual report on island fox care and monitoring provided in support of the San Nicolas Island seabird restoration program–2009. Unpublished report, Institute for Wildlife Studies, Arcata, CA.

Garcelon, D. K., and G. A. Schmidt. 2005. Island Fox Monitoring and Demography on San Nicolas Island–2004. Unpublished report prepared by the Institute for Wildlife Studies, Arcata, California. 24pp.

Garcelon, D. K., L. Munson, T.W. Vickers and D. Simmons. 2008. Research study on the pathology and veterinary services for island foxes on San Clemente Island. Final report under agreement N62473-06-LT-R0057, Naval Facilities Engineering Command, Southwest, San Diego, CA. 8 pages + Appendices.

Garcelon, D. K. and B. R. Hudgens. 2009. Island fox monitoring and demography on San Nicolas Island–2008. Unpublished report prepared by the Institute for Wildlife Studies, Arcata, California. 26pp.

Gilbert, D. A., N. Lehman, S. J. O'Brien, and R. K. Wayne. 1990. Genetic fingerprinting reflects population differentiation in the California Channel Island fox. Nature 344:764–767.

Goldstein, D. B., G. W. Roemer, D. A. Smith, D. E. Reich, A. Bergman, and R. K. Wayne. 1999. The use of microsatellite variation to infer patterns of migration, population structure, and demographic history: An evaluation of methods in a natural model system. Genetics 151:797–801.

Hall, E. R. 1981. The mammals of North America, 2nd ed. John Wiley and Sons, New York.

Halverson, W. L., S. Junak, C. Schwemm, and T. Keeney. 1996. Plant communities of San Nicolas Island, California. Technical Report No. 55. National Biological Service, University of Arizona, Tucson, Arizona.

Hanson, C.C., D.J. Will, J.E. Bonham, B.S. Keitt. 2010. Removal of feral cats from San Nicolas Island, California to protect native and endemic species: 2009 annual report. Unpublished report, Island Conservation, Santa Cruz, CA. 19pp.

Hudgens, B., F. Ferrara, and D. Garcelon. 2007. Remote monitoring of island foxes. Report to DoD Legacy Program, May 2007. 13pp.

Hudgens, B., F. Ferrara, and D. Garcelon. 2008. Digital radio-telemetry monitoring of San Nicolas Island foxes. Report to DoD Legacy Program, May 2007. 19pp.

Hudgens, B.R. and D. K. Garcelon. 2010. Island fox monitoring and demography on San Nicolas Island—2009. Unpublished report prepared by the Institute for Wildlife Studies, Arcata, California. 34pp.

Hudgens, B., D.K. Garcelon, J. Sanchez and T.W. Vickers. 2010. Epidemic response plan for San Clemente Island foxes. Unpublished report by the Institute for Wildlife Studies, Arcata, CA.

Johnson, J. B., and K. S. Omland. 2003. Model selection in ecology and evolution. Trends Ecol. Evol. 19:101–108.

Juola F. A., G. A. Schmidt, P. B. Sharpe, and D. K. Garcelon. 2002. Island Fox Monitoring and Demography on San Nicolas Island–2001. Unpublished report *prepared by* the Institute for Wildlife Studies, Arcata, California. 34pp.

Keller L. F., and D. M. Waller. 2002. Inbreeding effects in wild populations. TRENDS in Ecology and Evolution 17:230–241.

Kendall, W. L., K. H. Pollock, and C. Brownie. 1995. A likelihood-based approach to capture-recapture estimation of demographic parameters under the Robust Design. Biometrics 51:293–308.

Kendall, W. L. 2001. The Robust Design for capture-recapture studies: analysis using program MARK. Pages 357–360 in Proceedings of the 2nd International Wildlife Management Congress. The Wildlife Society, Bethesda, Maryland, USA.

Kohlmann, S. G., G. A. Schmidt, R. C. Wolstenholme, and D. K. Garcelon. 2003. Island fox recovery efforts on Santa Catalina Island, California, October 2001–October 2002, Annual Report. Unpublished report by the Institute for Wildlife Studies, Arcata, California for the Ecological Restoration Department, Santa Catalina Island Conservancy, Avalon, California. 83pp.

Kohlmann, S. G., G. A. Schmidt, and D. K. Garcelon. 2005. A population viability analysis for the Island Fox on Santa Catalina Island, California. Ecological Modeling 183:77–94.

Moore, C. M., and P. W. Collins. 1995. *Urocyon littoralis*. Mammalian Species, No. 489. 7pp.

Pollock, K. H. 1982. A capture-recapture design robust to unequal probability of capture. Journal of Wildlife Management 46:757–760.

Pollock, K. H., J. D. Nichols, J. E. Hines, and C. Brownie. 1990. Statistical inference for capture–recapture experiments. Wildlife Monographs 107.

Roemer, G. W., D. K. Garcelon, T. J. Coonan, and C. Schwemm. 1994. The use of capture-recapture methods for estimating, monitoring, and conserving island fox populations. Pages 387–400 in W. L. Halverson and G. J. Maender, editors. The Fourth California Channel Islands Symposium: Update on the Status of Resources. Santa Barbara Museum of Natural History, Santa Barbara, California.

Roemer, G. W., T. J. Coonan, D. K. Garcelon, J. Bascompte, and L. Laughrin. 2001. Feral pigs facilitate hyperpredation by golden eagles and indirectly cause the decline of the island fox. Animal Conservation 4:307–318.

Schmidt, G. A., and D. K. Garcelon. 2003. Island Fox Monitoring and Demography on San Nicolas Island–2002. Unpublished report *prepared by* the Institute for Wildlife Studies, Arcata, California. 22pp.

Schmidt, G. A., and D. K. Garcelon. 2004. Island Fox Monitoring and Demography on San Nicolas Island–2003. Unpublished report *prepared by* the Institute for Wildlife Studies, Arcata, California. 24pp.

Schmidt, G. A., B. Willson, and D. K. Garcelon. 2004. Island fox monitoring and research on Naval Auxiliary Landing Field, San Clemente Island, California. Unpublished report *prepared by* the Institute for Wildlife Studies, Arcata, California. 63pp.

Schmidt, G. A., B. R. Hudgens, and D. K. Garcelon. 2007. Island Fox Monitoring and Demography on San Nicolas Island–2006. Unpublished report *prepared by* the Institute for Wildlife Studies, Arcata, California. 26pp.

Schmidt, G. A., B. R. Hudgens, and D. K. Garcelon. 2006. Island Fox Monitoring and Demography on San Nicolas Island–2005. Unpublished report *prepared by* the Institute for Wildlife Studies, Arcata, California. 24pp.

Springbett, A. J., K. MacKenzie, J. A., Woolliams, and S. C. Bishop. 2003. The contribution of genetic diversity to the spread of infectious diseases in livestock populations. Genetics 165:1465–1474.

Suckling. K., and D. K. Garcelon. 2000. Petition to list four island fox subspecies as endangered species. Formal petition to list the San Miguel Island fox (*Urocyon littoralis littoralis*), Santa Rosa Island fox (*U. l. santarosae*), Santa Cruz Island fox (*U. l. santacruzae*), and the Santa Catalina Island fox (*U. l. catalinae*) as "endangered" throughout their range. *Prepared by* the Center for Biological Diversity, Tucson, Arizona and the Institute for Wildlife Studies, Arcata, California *for* the United States Department of the Interior and the United States Fish and Wildlife Service. 24pp.

Timm, S. F., J. M. Stokely, T. B. Gehr, R. L. Peebles, and D. K. Garcelon. 2000. Investigation into the decline of island foxes on Santa Catalina Island. Unpublished report *prepared by* the Institute for Wildlife Studies *for* the Ecological Restoration Department, Santa Catalina Island Conservancy, Avalon, California. 32pp.

Timm, S. F., L. Munson, B. Summers, K. Terio, E. Dubovi, C. Rupprecht, S. Kapil, and D. K. Garcelon. 2009. A suspected canine distemper epidemic as the cause of a catastrophic decline in Santa Catalina Island foxes (*Urocyon littoralis catalinae*). Journal of Wildlife Disease 45:333-343.

Trainer, D.O. and F.F. Knowlton. 1968. Serologic evidence of disease in Texas coyotes. Journal of Wildlife Diseases 32:981-983.

Wayne, R. K., S. B. George, D. Gilbert, P. W. Collins, S. D. Kovach, D. Girman, and N. Lehman. 1991. A morphologic and genetic study of the island fox, *Urocyon littoralis*. Evolution 45:1849–1868.

White, G. C. and K. P. Burnham. 1999. Program MARK: Survival estimation from populations of marked animals. Bird Study 46 Supplement 120–138.

Wilson, D. E., and D. M. Reeder. 1993. Mammal species of the World: a taxonomic and geographic reference, 2nd ed. Smithsonian Institution Press, Washington, DC.

Wilson, K. R., and D. R. Anderson. 1985. Evaluation of two density estimators of small mammal population size. Journal of Mammalogy 66:13–21.

Wood, J. E. 1958. Age structure and productivity of a gray fox population. Journal of Mammalogy 39:74–86.

Zarnke, R.L. and W.B. Ballard. 1987. Serological survey for selected microbial pathogens of wolves in Alaska, 1975-1982.Journal of Wildlife Diseases 23:77-85.

ACKNOWLEDGMENTS

This report was funded by the NAWCWD and the Department of the Navy under the administration of the Naval Facilities Engineering Command, Southwest, San Diego, California. We give special thanks to Grace Smith, SNI Natural Resources Manager, for her logistical support and valuable assistance to this project in a variety of ways. Gina Smith contributed logistical support on San Nicolas Island. We thank IWS employees Hower Blair, Kari Signor, Daniel Jackson, Thomas Thein, Julie Young and Jessica Sanchez for their assistance with the fieldwork.

APPENDIX A.

Island fox demography grids showing trap numbers and locations, San Nicolas Island, California.

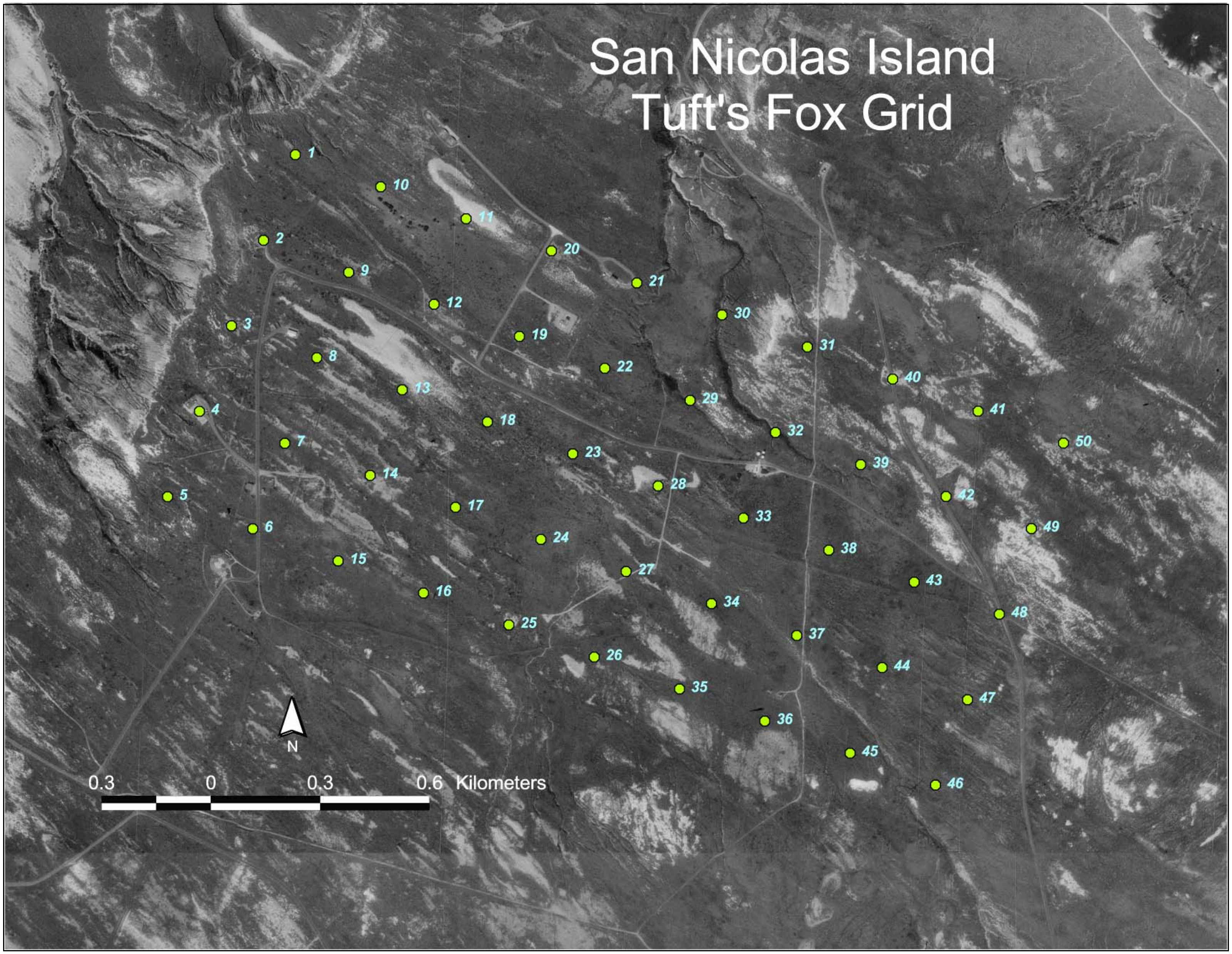

Figure A-1. Tuft's island fox demography grid, on Naval Base Ventura County, San Nicolas Island, California. Refer to figure 2 for location on island.

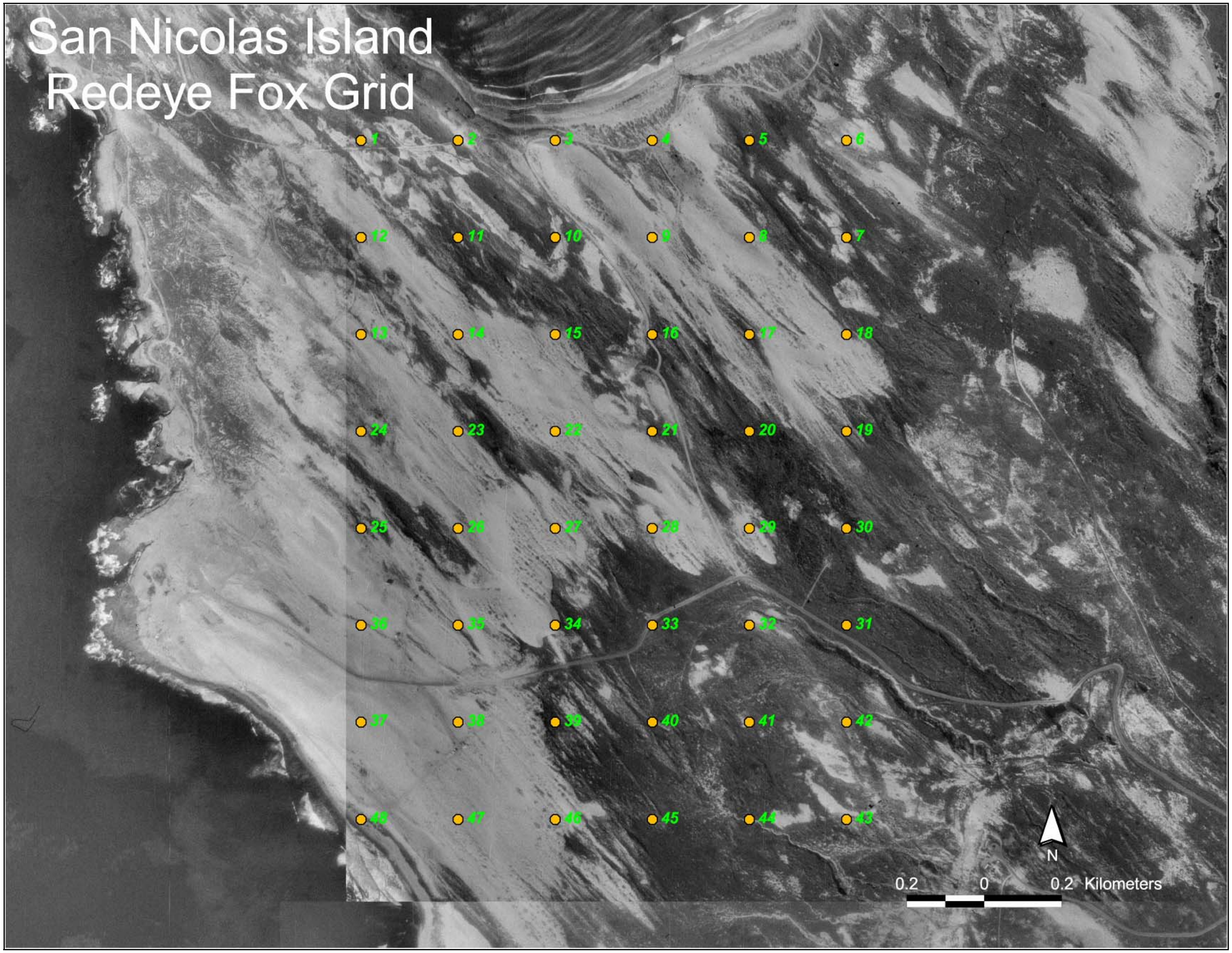

Figure A-2. Redeye island fox demography grid, on Naval Base Ventura County, San Nicolas Island, California. Refer to figure 2 for location on island.

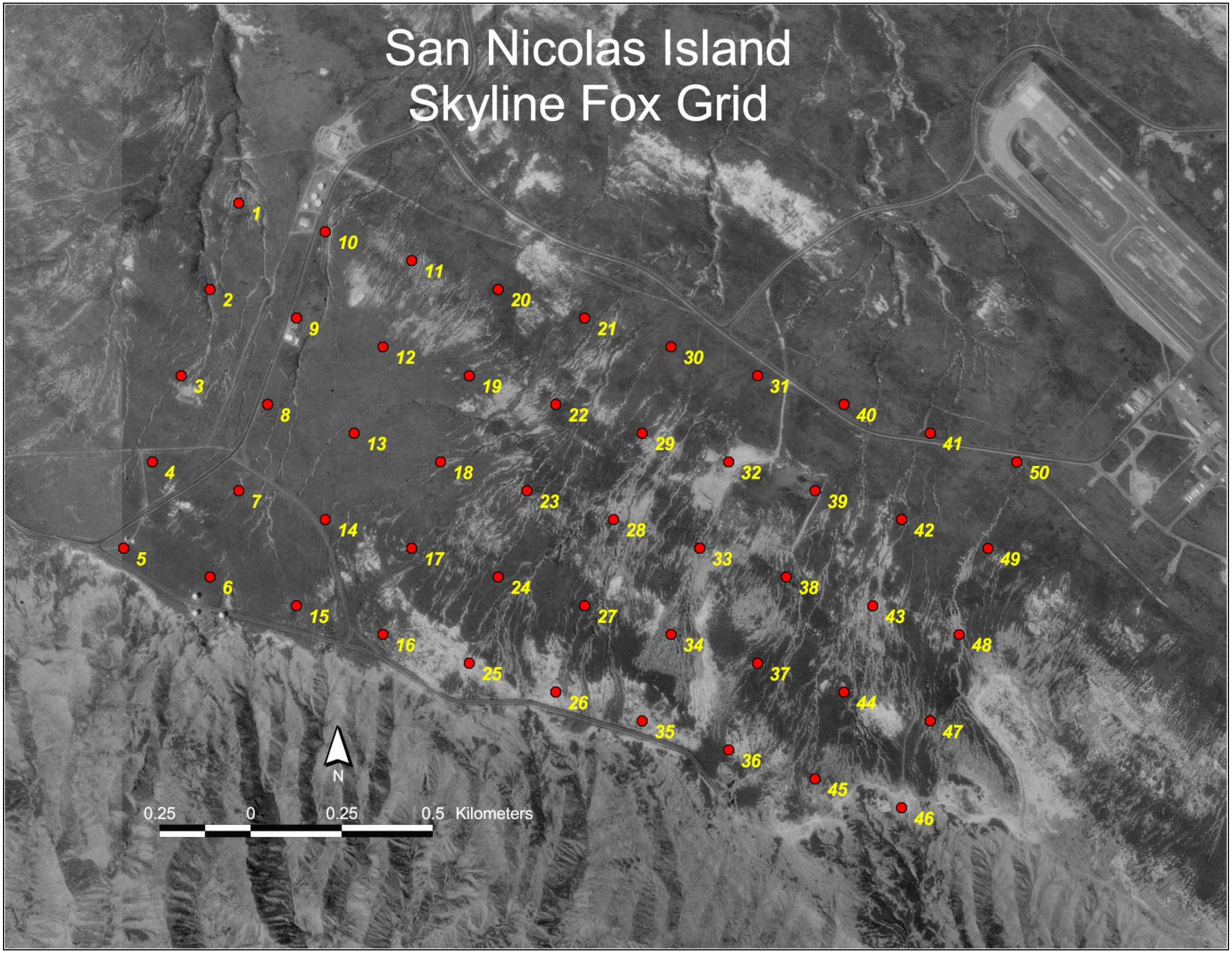

Figure A-3. Skyline island fox demography grid, on Naval Base Ventura County, San Nicolas Island, California. Refer to figure 2 for location on island.

APPENDIX B

Appendix B. Serological results for foxes sampled in 2010 for canine distemper virus (CDV), canine parvovirus (CPV) and canine adenovirus (CAV), and comparison of CAV values for foxes sampled in 2009 and 2010, on Naval Base Ventura County, San Nicolas Island, California.

Fox ID	CDV	CPV	CAV	
			2010	2009
86503	8	<20	3072	
35470	<8	<20	8192	
F7D66	<16	<20	1536	
25F28	<4	<20	3072	<4
36564	6	<20	6144	6
E6832	6	40	4096	4096
44246	4	<20	6144	6144
06D32	4	<20	<4	<4
50924	8	<20	2048	<4
5547	6	<20	3072	
15378	6	<20	384	
16529	<4	<20	6144	
26444	<4	<20	<4	
41531	<4	<20	6144	
42079	4	<20	3072	
46872	4	<20	<4	
52878	6	<20	8192	
61821	6	40	>=12288	
90810	4	<20	>=12288	
95963	6	<20	3072	3072
96577	<4	<20	6144	
23B71	4	<20	<4	
3003F	4	<20	>=12288	
4162D	12	<20	<4	
4296A	4	<20	<4	
4777B	64[1]	<20	3072	
5197E	<4	<20	<4	
A142E	<4	<20	<4	
A2B7E	6	<20	4	
A3248	16	<20	1536	6
B1B0B	<4	<20	1024	<4
B1C31	6	<20	8192	
B7767	6	<20	<4	
C6778	12	<20	6144	
C7A2C	<8	<20	>=12288	<4
D0A67	4	20	3072	
D2810	4	<20	<4	
D4B11	4	<20	<4	
E5279	4	<20	6144	
F5124	24[1]	<20	3072	
4701E	<4	<20	4096	
5451B	4	40	3072	
B3232	6	<20	3072	
63048	6	<20	4096	
15E22	4	<20	3072	<4
7285A	4	40	6144	
C1275	<4	<20	>=12288	
3423F	4	<20	768	

[1]Fox was previously vaccinated for CDV.